

# LIGHT QUARKS ( $u, d, s$ )

OMITTED FROM SUMMARY TABLE

## $u$ -QUARK MASS

The  $u$ -,  $d$ -, and  $s$ -quark masses are estimates of so-called "current-quark masses," in a mass-independent subtraction scheme such as  $\overline{MS}$ . The ratios  $m_u/m_d$  and  $m_s/m_d$  are extracted from pion and kaon masses using chiral symmetry. The estimates of  $d$  and  $u$  masses are not without controversy and remain under active investigation. Within the literature there are even suggestions that the  $u$  quark could be essentially massless. The  $s$ -quark mass is estimated from SU(3) splittings in hadron masses.

We have normalized the  $\overline{MS}$  masses at a renormalization scale of  $\mu = 2$  GeV. Results quoted in the literature at  $\mu = 1$  GeV have been rescaled by dividing by 1.35. The values of "Our Evaluation" were determined in part via Figures 1 and 2.

| VALUE (MeV) | DOCUMENT ID | TECN | COMMENT |
|-------------|-------------|------|---------|
|-------------|-------------|------|---------|

### 2.3 $^{+0.7}_{-0.5}$ OUR EVALUATION See the ideogram below.

Average is meaningless. See the ideogram below.  $[2.27 \pm 0.14 \text{ MeV OUR 2012 AVERAGE Scale factor} = 2.1]$

|                          |                        |    |      |                        |
|--------------------------|------------------------|----|------|------------------------|
| $2.15 \pm 0.03 \pm 0.10$ | <sup>1</sup> DURR      | 11 | LATT | $\overline{MS}$ scheme |
| $2.24 \pm 0.10 \pm 0.34$ | <sup>2</sup> BLUM      | 10 | LATT | $\overline{MS}$ scheme |
| $2.01 \pm 0.14$          | <sup>3</sup> MCNEILE   | 10 | LATT | $\overline{MS}$ scheme |
| $2.9 \pm 0.2$            | <sup>4</sup> DOMINGUEZ | 09 | THEO | $\overline{MS}$ scheme |
| $2.7 \pm 0.4$            | <sup>5</sup> JAMIN     | 06 | THEO | $\overline{MS}$ scheme |
| $1.9 \pm 0.2$            | <sup>6</sup> MASON     | 06 | LATT | $\overline{MS}$ scheme |
| $2.8 \pm 0.2$            | <sup>7</sup> NARISON   | 06 | THEO | $\overline{MS}$ scheme |

• • • We do not use the following data for averages, fits, limits, etc. • • •

|                 |                       |     |      |                        |
|-----------------|-----------------------|-----|------|------------------------|
| $2.01 \pm 0.14$ | <sup>3</sup> DAVIES   | 10  | LATT | $\overline{MS}$ scheme |
| $2.9 \pm 0.8$   | <sup>8</sup> DEANDREA | 08  | THEO | $\overline{MS}$ scheme |
| $3.02 \pm 0.33$ | <sup>9</sup> BLUM     | 07  | LATT | $\overline{MS}$ scheme |
| $1.7 \pm 0.3$   | <sup>10</sup> AUBIN   | 04A | LATT | $\overline{MS}$ scheme |

<sup>1</sup> DURR 11 determine quark mass from a lattice computation of the meson spectrum using  $N_f = 2 + 1$  dynamical flavors. The lattice simulations were done at the physical quark mass, so that extrapolation in the quark mass was not needed. The individual  $m_u, m_d$  values are obtained using the lattice determination of the average mass  $m_{ud}$  and of the ratio  $m_s/m_{ud}$  and the value of  $Q = (m_s^2 - m_{ud}^2) / (m_d^2 - m_u^2)$  as determined from  $\eta \rightarrow 3\pi$  decays.

<sup>2</sup> BLUM 10 determines light quark masses using a QCD plus QED lattice computation of the electromagnetic mass splittings of the low-lying hadrons. The lattice simulations use 2+1 dynamical quark flavors.

<sup>3</sup> DAVIES 10 and MCNEILE 10 determine  $\overline{m}_c(\mu)/\overline{m}_s(\mu) = 11.85 \pm 0.16$  using a lattice computation with  $N_f = 2 + 1$  dynamical fermions of the pseudoscalar meson masses. Mass  $m_u$  is obtained from this using the value of  $m_c$  from ALLISON 08 or MCNEILE 10 and the BAZAVOV 10 values for the light quark mass ratios,  $m_s/\overline{m}$  and  $m_u/m_d$ .

<sup>4</sup> DOMINGUEZ 09 use QCD finite energy sum rules for the two-point function of the divergence of the axial vector current computed to order  $\alpha_s^4$ .

<sup>5</sup> JAMIN 06 determine  $m_u(2 \text{ GeV})$  by combining the value of  $m_s$  obtained from the spectral function for the scalar  $K\pi$  form factor with other determinations of the quark mass ratios.

<sup>6</sup> MASON 06 extract light quark masses from a lattice simulation using staggered fermions with an improved action, and three dynamical light quark flavors with degenerate  $u$  and  $d$  quarks. Perturbative corrections were included at NNLO order. The quark masses  $m_u$  and  $m_d$  were determined from their  $(m_u + m_d)/2$  measurement and AUBIN 04A  $m_u/m_d$  value.

<sup>7</sup> NARISON 06 uses sum rules for  $e^+ e^- \rightarrow \text{hadrons}$  to order  $\alpha_s^3$  to determine  $m_s$  combined with other determinations of the quark mass ratios.

<sup>8</sup> DEANDREA 08 determine  $m_u - m_d$  from  $\eta \rightarrow 3\pi^0$ , and combine with the PDG 06 lattice average value of  $m_u + m_d = 7.6 \pm 1.6$  to determine  $m_u$  and  $m_d$ .

<sup>9</sup> BLUM 07 determine quark masses from the pseudoscalar meson masses using a QED plus QCD lattice computation with two dynamical quark flavors.

<sup>10</sup> AUBIN 04A employ a partially quenched lattice calculation of the pseudoscalar meson masses.

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NODE=Q123UM

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NODE=Q123UM;LINKAGE=DU

NODE=Q123UM;LINKAGE=BU

NODE=Q123UM;LINKAGE=DA

NODE=Q123UM;LINKAGE=DM

NODE=Q123UM;LINKAGE=JM

NODE=Q123UM;LINKAGE=MA

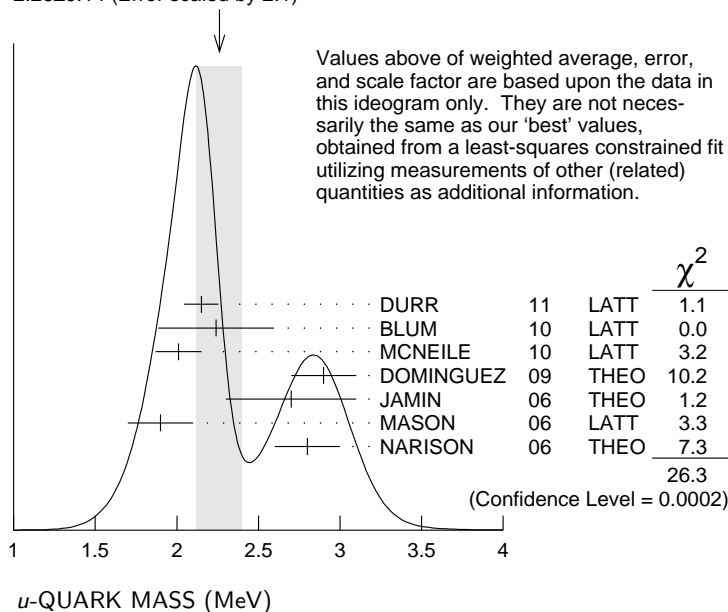
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NODE=Q123UM;LINKAGE=DE

NODE=Q123UM;LINKAGE=BL

NODE=Q123UM;LINKAGE=AU

WEIGHTED AVERAGE  
2.26±0.14 (Error scaled by 2.1)



## d-QUARK MASS

See the comment for the  $u$  quark above.

We have normalized the  $\overline{MS}$  masses at a renormalization scale of  $\mu = 2$  GeV. Results quoted in the literature at  $\mu = 1$  GeV have been rescaled by dividing by 1.35. The values of "Our Evaluation" were determined in part via Figures 1 and 2.

| VALUE (MeV)   | DOCUMENT ID   | TECN     | COMMENT                |
|---|---|----------|------------------------|
| <b>4.8<sup>+0.5</sup><sub>-0.3</sub> OUR EVALUATION</b>                       | See the ideogram below. [4.8 <sup>+0.7</sup> <sub>-0.3</sub> MeV OUR 2012 EVALUATION] |          |                        |
| 4.79±0.07±0.12  | 11 DURR   | 11 LATT  | $\overline{MS}$ scheme |
| 4.65±0.15±0.32  | 12 BLUM   | 10 LATT  | $\overline{MS}$ scheme |
| 4.77±0.15   | 13 MCNEILE  | 10 LATT  | $\overline{MS}$ scheme |
| 5.3 ±0.4  | 14 DOMINGUEZ  | 09 THEO  | $\overline{MS}$ scheme |
| 4.8 ±0.5  | 15 JAMIN  | 06 THEO  | $\overline{MS}$ scheme |
| 4.4 ±0.3  | 16 MASON  | 06 LATT  | $\overline{MS}$ scheme |
| 5.1 ±0.4  | 17 NARISON  | 06 THEO  | $\overline{MS}$ scheme |
| • • • We do not use the following data for averages, fits, limits, etc. • • • |   |          |                        |
| 4.79±0.16   | 13 DAVIES   | 10 LATT  | $\overline{MS}$ scheme |
| 4.7 ±0.8  | 18 DEANDREA   | 08 THEO  | $\overline{MS}$ scheme |
| 5.49±0.39   | 19 BLUM   | 07 LATT  | $\overline{MS}$ scheme |
| 3.9 ±0.5  | 20 AUBIN  | 04A LATT | $\overline{MS}$ scheme |

- 11 DURR 11 determine quark mass from a lattice computation of the meson spectrum using  $N_f = 2 + 1$  dynamical flavors. The lattice simulations were done at the physical quark mass, so that extrapolation in the quark mass was not needed. The individual  $m_u$ ,  $m_d$  values are obtained using the lattice determination of the average mass  $m_{ud}$  and of the ratio  $m_s/m_{ud}$  and the value of  $Q = (m_s^2 - m_{ud}^2) / (m_d^2 - m_u^2)$  as determined from  $\eta \rightarrow 3\pi$  decays.
- 12 BLUM 10 determines light quark masses using a QCD plus QED lattice computation of the electromagnetic mass splittings of the low-lying hadrons. The lattice simulations use 2+1 dynamical quark flavors.
- 13 DAVIES 10 and MCNEILE 10 determine  $\overline{m}_c(\mu)/\overline{m}_s(\mu) = 11.85 \pm 0.16$  using a lattice computation with  $N_f = 2 + 1$  dynamical fermions of the pseudoscalar meson masses. Mass  $m_d$  is obtained from this using the value of  $m_c$  from ALLISON 08 or MCNEILE 10 and the BAZAVOV 10 values for the light quark mass ratios,  $m_s/\overline{m}$  and  $m_u/m_d$ .
- 14 DOMINGUEZ 09 use QCD finite energy sum rules for the two-point function of the divergence of the axial vector current computed to order  $\alpha_s^4$ .
- 15 JAMIN 06 determine  $m_d(2 \text{ GeV})$  by combining the value of  $m_s$  obtained from the spectral function for the scalar  $K\pi$  form factor with other determinations of the quark mass ratios.
- 16 MASON 06 extract light quark masses from a lattice simulation using staggered fermions with an improved action, and three dynamical light quark flavors with degenerate  $u$  and  $d$  quarks. Perturbative corrections were included at NNLO order. The quark masses

NODE=Q123DM

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NODE=Q123DM

NEW;→ UNCHECKED ←

NODE=Q123DM;LINKAGE=DU

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NODE=Q123DM;LINKAGE=DA

NODE=Q123DM;LINKAGE=DM

NODE=Q123DM;LINKAGE=JM

NODE=Q123DM;LINKAGE=MA

$m_u$  and  $m_d$  were determined from their  $(m_u+m_d)/2$  measurement and AUBIN 04A  $m_u/m_d$  value.

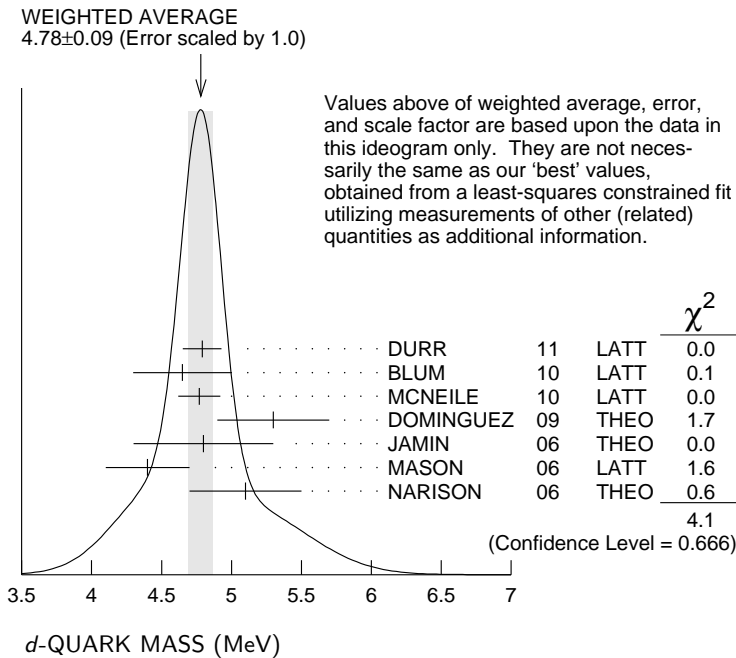
- 17 NARISON 06 uses sum rules for  $e^+e^- \rightarrow \text{hadrons}$  to order  $\alpha_s^3$  to determine  $m_s$  combined with other determinations of the quark mass ratios.
- 18 DEANDREA 08 determine  $m_u-m_d$  from  $\eta \rightarrow 3\pi^0$ , and combine with the PDG 06 lattice average value of  $m_u+m_d = 7.6 \pm 1.6$  to determine  $m_u$  and  $m_d$ .
- 19 BLUM 07 determine quark masses from the pseudoscalar meson masses using a QED plus QCD lattice computation with two dynamical quark flavors.
- 20 AUBIN 04A perform three flavor dynamical lattice calculation of pseudoscalar meson masses, with continuum estimate of electromagnetic effects in the kaon masses, and one-loop perturbative renormalization constant.

NODE=Q123DM;LINKAGE=NA

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NODE=Q123DM;LINKAGE=BL

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$$\bar{m} = (m_u+m_d)/2$$

NODE=Q123MR4

NODE=Q123MR4

See the comments for the  $u$  quark above.

We have normalized the  $\overline{MS}$  masses at a renormalization scale of  $\mu = 2$  GeV. Results quoted in the literature at  $\mu = 1$  GeV have been rescaled by dividing by 1.35. The values of "Our Evaluation" were determined in part via Figures 1 and 2.

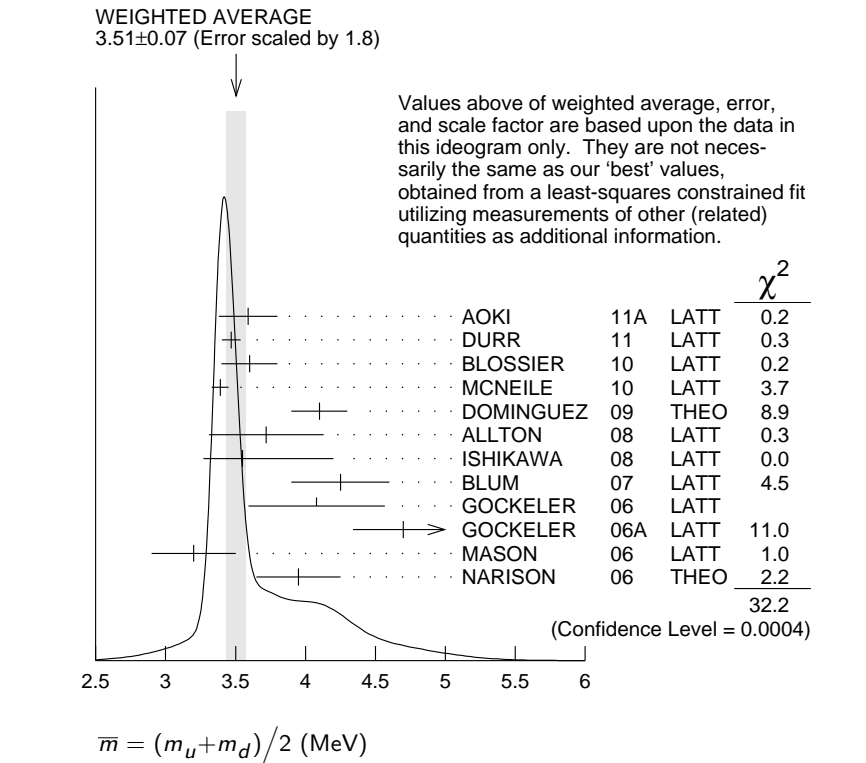
| VALUE (MeV)                              | DOCUMENT ID           | TECN     | COMMENT                                       |
|--|-----------------------|----------|---|
| <b>3.5 <math>\pm 0.7</math><br/>-0.2</b> | <b>OUR EVALUATION</b> |          | See the ideogram below. [3.2-4.4 MeV OUR 2012 |
| EVALUATION]                              |                       |          |   |
| 3.59 $\pm 0.21$                          | 21 AOKI               | 11A LATT | $\overline{MS}$ scheme                        |
| 3.469 $\pm 0.047 \pm 0.048$              | 22 DURR               | 11 LATT  | $\overline{MS}$ scheme                        |
| 3.6 $\pm 0.2$                            | 23 BLOSSIER           | 10 LATT  | $\overline{MS}$ scheme                        |
| 3.39 $\pm 0.06$                          | 24 MCNEILE            | 10 LATT  | $\overline{MS}$ scheme                        |
| 4.1 $\pm 0.2$                            | 25 DOMINGUEZ          | 09 THEO  | $\overline{MS}$ scheme                        |
| 3.72 $\pm 0.41$                          | 26 ALLTON             | 08 LATT  | $\overline{MS}$ scheme                        |
| 3.55 $\pm 0.65$<br>-0.28                 | 27 ISHIKAWA           | 08 LATT  | $\overline{MS}$ scheme                        |
| 4.25 $\pm 0.35$                          | 28 BLUM               | 07 LATT  | $\overline{MS}$ scheme                        |
| 4.08 $\pm 0.25 \pm 0.42$                 | 29 GOCKELER           | 06 LATT  | $\overline{MS}$ scheme                        |
| 4.7 $\pm 0.2 \pm 0.3$                    | 30 GOCKELER           | 06A LATT | $\overline{MS}$ scheme                        |
| 3.2 $\pm 0.3$                            | 31 MASON              | 06 LATT  | $\overline{MS}$ scheme                        |
| 3.95 $\pm 0.3$                           | 32 NARISON            | 06 THEO  | $\overline{MS}$ scheme                        |

NODE=Q123MR4

NEW;→ UNCHECKED ←

• • • We do not use the following data for averages, fits, limits, etc. • • •

|   |                               |      |                        |                        |                         |
|---|-------------------------------|------|------------------------|------------------------|-------------------------|
| 3.40 ±0.07  | <sup>24</sup> DAVIES          | 10   | LATT                   | $\overline{MS}$ scheme |                         |
| 3.85 ±0.12 ±0.4   | <sup>33</sup> BLOSSIER        | 08   | LATT                   | $\overline{MS}$ scheme |                         |
| ≥ 4.85 ±0.20  | <sup>34</sup> DOMINGUEZ...08B | THEO | $\overline{MS}$ scheme |                        |                         |
| 4.026±0.048   | <sup>35</sup> NAKAMURA        | 08   | LATT                   | $\overline{MS}$ scheme |                         |
| 2.8 ±0.3  | <sup>36</sup> AUBIN           | 04   | LATT                   | $\overline{MS}$ scheme |                         |
| 4.29 ±0.14 ±0.65  | <sup>37</sup> AOKI            | 03   | LATT                   | $\overline{MS}$ scheme |                         |
| 3.223±0.3   | <sup>38</sup> AOKI            | 03B  | LATT                   | $\overline{MS}$ scheme |                         |
| 4.4 ±0.1 ±0.4   | <sup>39</sup> BECIREVIC       | 03   | LATT                   | $\overline{MS}$ scheme |                         |
| 4.1 ±0.3 ±1.0   | <sup>40</sup> CHIU            | 03   | LATT                   | $\overline{MS}$ scheme |                         |
| <sup>21</sup> AOKI 11A determine quark masses from a lattice computation of the hadron spectrum using $N_f = 2 + 1$ dynamical flavors of domain wall fermions.  |                               |      |                        |                        | NODE=Q123MR4;LINKAGE=OK |
| <sup>22</sup> DURR 11 determine quark mass from a lattice computation of the meson spectrum using $N_f = 2 + 1$ dynamical flavors. The lattice simulations were done at the physical quark mass, so that extrapolation in the quark mass was not needed.  |                               |      |                        |                        | NODE=Q123MR4;LINKAGE=DU |
| <sup>23</sup> BLOSSIER 10 determines quark masses from a computation of the hadron spectrum using $N_f=2$ dynamical twisted-mass Wilson fermions.   |                               |      |                        |                        | NODE=Q123MR4;LINKAGE=BS |
| <sup>24</sup> DAVIES 10 and MCNEILE 10 determine $\overline{m}_C(\mu)/\overline{m}_S(\mu) = 11.85 \pm 0.16$ using a lattice computation with $N_f = 2 + 1$ dynamical fermions of the pseudoscalar meson masses. Mass $\overline{m}$ is obtained from this using the value of $m_C$ from ALLISON 08 or MCNEILE 10 and the BAZAVOV 10 values for the light quark mass ratio, $m_S/\overline{m}$ .   |                               |      |                        |                        | NODE=Q123MR4;LINKAGE=DA |
| <sup>25</sup> DOMINGUEZ 09 use QCD finite energy sum rules for the two-point function of the divergence of the axial vector current computed to order $\alpha_s^4$ .  |                               |      |                        |                        | NODE=Q123MR4;LINKAGE=DM |
| <sup>26</sup> ALLTON 08 use a lattice computation of the $\pi$ , $K$ , and $\Omega$ masses with 2+1 dynamical flavors of domain wall quarks, and non-perturbative renormalization.  |                               |      |                        |                        | NODE=Q123MR4;LINKAGE=LT |
| <sup>27</sup> ISHIKAWA 08 use a lattice computation of the light meson spectrum with 2+1 dynamical flavors of $\mathcal{O}(a)$ improved Wilson quarks, and one-loop perturbative renormalization.   |                               |      |                        |                        | NODE=Q123MR4;LINKAGE=IS |
| <sup>28</sup> BLUM 07 determine quark masses from the pseudoscalar meson masses using a QED plus QCD lattice computation with two dynamical quark flavors.  |                               |      |                        |                        | NODE=Q123MR4;LINKAGE=BL |
| <sup>29</sup> GOCKELER 06 use an unquenched lattice computation of the axial Ward Identity with $N_f = 2$ dynamical light quark flavors, and non-perturbative renormalization, to obtain $\overline{m}(2 \text{ GeV}) = 4.08 \pm 0.25 \pm 0.19 \pm 0.23 \text{ MeV}$ , where the first error is statistical, the second and third are systematic due to the fit range and force scale uncertainties, respectively. We have combined the systematic errors linearly. |                               |      |                        |                        | NODE=Q123MR4;LINKAGE=CK |
| <sup>30</sup> GOCKELER 06A use an unquenched lattice computation of the pseudoscalar meson masses with $N_f = 2$ dynamical light quark flavors, and non-perturbative renormalization.   |                               |      |                        |                        | NODE=Q123MR4;LINKAGE=GO |
| <sup>31</sup> MASON 06 extract light quark masses from a lattice simulation using staggered fermions with an improved action, and three dynamical light quark flavors with degenerate $u$ and $d$ quarks. Perturbative corrections were included at NNLO order.   |                               |      |                        |                        | NODE=Q123MR4;LINKAGE=MA |
| <sup>32</sup> NARISON 06 uses sum rules for $e^+ e^- \rightarrow \text{hadrons}$ to order $\alpha_s^3$ to determine $m_S$ combined with other determinations of the quark mass ratios.  |                               |      |                        |                        | NODE=Q123MR4;LINKAGE=NA |
| <sup>33</sup> BLOSSIER 08 use a lattice computation of pseudoscalar meson masses and decay constants with 2 dynamical flavors and non-perturbative renormalization.   |                               |      |                        |                        | NODE=Q123MR4;LINKAGE=BO |
| <sup>34</sup> DOMINGUEZ-CLARIMON 08B obtain an inequality from sum rules for the scalar two-point correlator.   |                               |      |                        |                        | NODE=Q123MR4;LINKAGE=DO |
| <sup>35</sup> NAKAMURA 08 do a lattice computation using quenched domain wall fermions and non-perturbative renormalization.  |                               |      |                        |                        | NODE=Q123MR4;LINKAGE=NM |
| <sup>36</sup> AUBIN 04 perform three flavor dynamical lattice calculation of pseudoscalar meson masses, with one-loop perturbative renormalization constant.  |                               |      |                        |                        | NODE=Q123MR4;LINKAGE=AU |
| <sup>37</sup> AOKI 03 uses quenched lattice simulation of the meson and baryon masses with degenerate light quarks. The extrapolations are done using quenched chiral perturbation theory.  |                               |      |                        |                        | NODE=Q123MR4;LINKAGE=AO |
| <sup>38</sup> The errors given in AOKI 03B were $\begin{smallmatrix} +0.046 \\ -0.069 \end{smallmatrix}$ . We changed them to $\pm 0.3$ for calculating the overall best values. AOKI 03B uses lattice simulation of the meson and baryon masses with two dynamical light quarks. Simulations are performed using the $\mathcal{O}(a)$ improved Wilson action.  |                               |      |                        |                        | NODE=Q123MR4;LINKAGE=AI |
| <sup>39</sup> BECIREVIC 03 perform quenched lattice computation using the vector and axial Ward identities. Uses $\mathcal{O}(a)$ improved Wilson action and nonperturbative renormalization.   |                               |      |                        |                        | NODE=Q123MR4;LINKAGE=BE |
| <sup>40</sup> CHIU 03 determines quark masses from the pion and kaon masses using a lattice simulation with a chiral fermion action in quenched approximation.  |                               |      |                        |                        | NODE=Q123MR4;LINKAGE=CH |



**$m_u/m_d$  MASS RATIO**

| VALUE   | DOCUMENT ID             | TECN     | COMMENT     |
|---|-------------------------|----------|-------------|
| <b>0.38-0.58 OUR EVALUATION</b>   | See the ideogram below. |          |             |
| 0.550±0.031   | <sup>41</sup> BLUM      | 07 LATT  |             |
| 0.43 ±0.08  | <sup>42</sup> AUBIN     | 04A LATT |             |
| 0.410±0.036   | <sup>43</sup> NELSON    | 03 LATT  |             |
| 0.553±0.043   | <sup>44</sup> LEUTWYLER | 96 THEO  | Compilation |
| <sup>41</sup> BLUM 07 determine quark masses from the pseudoscalar meson masses using a QED plus QCD lattice computation with two dynamical quark flavors.  |                         |          |             |
| <sup>42</sup> AUBIN 04A perform three flavor dynamical lattice calculation of pseudoscalar meson masses, with continuum estimate of electromagnetic effects in the kaon masses.   |                         |          |             |
| <sup>43</sup> NELSON 03 computes coefficients in the order $p^4$ chiral Lagrangian using a lattice calculation with three dynamical flavors. The ratio $m_u/m_d$ is obtained by combining this with the chiral perturbation theory computation of the meson masses to order $p^4$ . |                         |          |             |
| <sup>44</sup> LEUTWYLER 96 uses a combined fit to $\eta \rightarrow 3\pi$ and $\psi' \rightarrow J/\psi (\pi,\eta)$ decay rates, and the electromagnetic mass differences of the $\pi$ and $K$ .  |                         |          |             |

NODE=Q123MR0

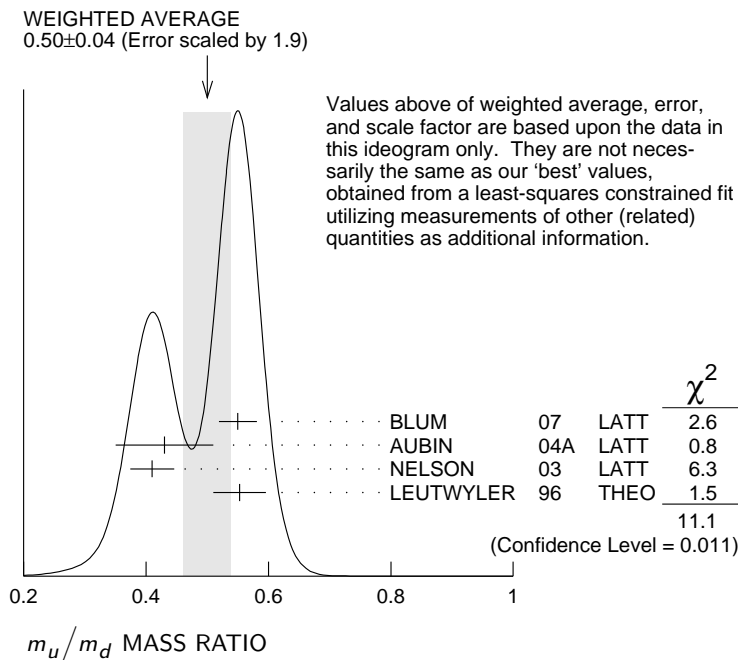
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→ UNCHECKED ←

NODE=Q123MR0;LINKAGE=BL

NODE=Q123MR0;LINKAGE=AU

NODE=Q123MR0;LINKAGE=N

NODE=Q123MR0;LINKAGE=M



### s-QUARK MASS

See the comment for the  $u$  quark above.

We have normalized the  $\overline{MS}$  masses at a renormalization scale of  $\mu = 2$  GeV. Results quoted in the literature at  $\mu = 1$  GeV have been rescaled by dividing by 1.35.

NODE=Q123SM

NODE=Q123SM

VALUE (MeV) DOCUMENT ID TECN COMMENT  
**95 ± 5 OUR EVALUATION** See the ideogram below.

Average is meaningless. See the ideogram below. [94.3 ± 1.2 MeV OUR 2012 AVERAGE Scale factor = 1.3]

|                     |    |           |     |      |                        |
|---------------------|----|-----------|-----|------|------------------------|
| 102 ± 3 ± 1         | 45 | FRITZSCH  | 12  | LATT | $\overline{MS}$ scheme |
| 96.2 ± 2.7          | 46 | AOKI      | 11A | LATT | $\overline{MS}$ scheme |
| 95.5 ± 1.1 ± 1.5    | 47 | DURR      | 11  | LATT | $\overline{MS}$ scheme |
| 95 ± 6              | 48 | BLOSSIER  | 10  | LATT | $\overline{MS}$ scheme |
| 97.6 ± 2.9 ± 5.5    | 49 | BLUM      | 10  | LATT | $\overline{MS}$ scheme |
| 92.2 ± 1.3          | 50 | MCNEILE   | 10  | LATT | $\overline{MS}$ scheme |
| 107.3 ± 11.7        | 51 | ALLTON    | 08  | LATT | $\overline{MS}$ scheme |
| 102 ± 8             | 52 | DOMINGUEZ | 08A | THEO | $\overline{MS}$ scheme |
| 90.1 +17.2<br>- 6.1 | 53 | ISHIKAWA  | 08  | LATT | $\overline{MS}$ scheme |
| 105 ± 6 ± 7         | 54 | CHETYRKIN | 06  | THEO | $\overline{MS}$ scheme |
| 111 ± 6 ± 10        | 55 | GOCKELER  | 06  | LATT | $\overline{MS}$ scheme |
| 119 ± 5 ± 8         | 56 | GOCKELER  | 06A | LATT | $\overline{MS}$ scheme |
| 92 ± 9              | 57 | JAMIN     | 06  | THEO | $\overline{MS}$ scheme |
| 87 ± 6              | 58 | MASON     | 06  | LATT | $\overline{MS}$ scheme |
| 104 ± 15            | 59 | NARISON   | 06  | THEO | $\overline{MS}$ scheme |

• • • We do not use the following data for averages, fits, limits, etc. • • •

|                       |    |           |     |      |                        |
|-----------------------|----|-----------|-----|------|------------------------|
| 92.4 ± 1.5            | 50 | DAVIES    | 10  | LATT | $\overline{MS}$ scheme |
| 105 ± 3 ± 9           | 60 | BLOSSIER  | 08  | LATT | $\overline{MS}$ scheme |
| 105.6 ± 1.2           | 61 | NAKAMURA  | 08  | LATT | $\overline{MS}$ scheme |
| 119.5 ± 9.3           | 62 | BLUM      | 07  | LATT | $\overline{MS}$ scheme |
| ≥ 71 ± 4, ≤ 151 ± 14  | 63 | NARISON   | 06  | THEO | $\overline{MS}$ scheme |
| 96 + 5 +16<br>- 3 -18 | 64 | BAIKOV    | 05  | THEO | $\overline{MS}$ scheme |
| 81 ± 22               | 65 | GAMIZ     | 05  | THEO | $\overline{MS}$ scheme |
| 125 ± 28              | 66 | GORBUNOV  | 05  | THEO | $\overline{MS}$ scheme |
| 93 ± 32               | 67 | NARISON   | 05  | THEO | $\overline{MS}$ scheme |
| 76 ± 8                | 68 | AUBIN     | 04  | LATT | $\overline{MS}$ scheme |
| 116 ± 6 ± 0.65        | 69 | AOKI      | 03  | LATT | $\overline{MS}$ scheme |
| 84.5 +12<br>- 1.7     | 70 | AOKI      | 03B | LATT | $\overline{MS}$ scheme |
| 106 ± 2 ± 8           | 71 | BECIREVIC | 03  | LATT | $\overline{MS}$ scheme |
| 92 ± 9 ± 16           | 72 | CHIU      | 03  | LATT | $\overline{MS}$ scheme |
| 117 ± 17              | 73 | GAMIZ     | 03  | THEO | $\overline{MS}$ scheme |
| 103 ± 17              | 74 | GAMIZ     | 03  | THEO | $\overline{MS}$ scheme |

NODE=Q123SM

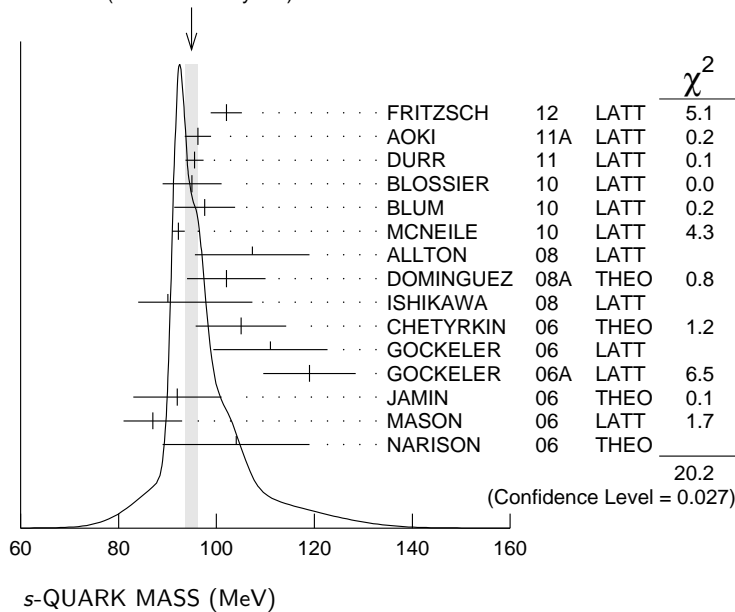
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|   |                        |
|---|------------------------|
| 45 FRITZSCH 12 determine $m_s$ using a lattice computation with $N_f = 2$ dynamical flavors.  | NODE=Q123SM;LINKAGE=FR |
| 46 AOKI 11A determine quark masses from a lattice computation of the hadron spectrum using $N_f = 2 + 1$ dynamical flavors of domain wall fermions.   | NODE=Q123SM;LINKAGE=OK |
| 47 DURR 11 determine quark mass from a lattice computation of the meson spectrum using $N_f = 2 + 1$ dynamical flavors. The lattice simulations were done at the physical quark mass, so that extrapolation in the quark mass was not needed.   | NODE=Q123SM;LINKAGE=DU |
| 48 BLOSSIER 10 determines quark masses from a computation of the hadron spectrum using $N_f=2$ dynamical twisted-mass Wilson fermions.  | NODE=Q123SM;LINKAGE=BS |
| 49 BLUM 10 determines light quark masses using a QCD plus QED lattice computation of the electromagnetic mass splittings of the low-lying hadrons. The lattice simulations use 2+1 dynamical quark flavors.   | NODE=Q123SM;LINKAGE=BU |
| 50 DAVIES 10 and MCNEILE 10 determine $\bar{m}_C(\mu)/\bar{m}_S(\mu) = 11.85 \pm 0.16$ using a lattice computation with $N_f = 2 + 1$ dynamical fermions of the pseudoscalar meson masses. Mass $m_s$ is obtained from this using the value of $m_C$ from ALLISON 08 or MCNEILE 10.   | NODE=Q123SM;LINKAGE=DA |
| 51 ALLTON 08 use a lattice computation of the $\pi$ , $K$ , and $\Omega$ masses with 2+1 dynamical flavors of domain wall quarks, and non-perturbative renormalization.   | NODE=Q123SM;LINKAGE=LT |
| 52 DOMINGUEZ 08A make determination from QCD finite energy sum rules for the pseudoscalar two-point function computed to order $\alpha_s^4$ .   | NODE=Q123SM;LINKAGE=DO |
| 53 ISHIKAWA 08 use a lattice computation of the light meson spectrum with 2+1 dynamical flavors of $\mathcal{O}(a)$ improved Wilson quarks, and one-loop perturbative renormalization.  | NODE=Q123SM;LINKAGE=IS |
| 54 CHETYRKIN 06 use QCD sum rules in the pseudoscalar channel to order $\alpha_s^4$ .   | NODE=Q123SM;LINKAGE=HE |
| 55 GOCKELER 06 use an unquenched lattice computation of the axial Ward Identity with $N_f = 2$ dynamical light quark flavors, and non-perturbative renormalization, to obtain $\bar{m}_s(2 \text{ GeV}) = 111 \pm 6 \pm 4 \pm 6 \text{ MeV}$ , where the first error is statistical, the second and third are systematic due to the fit range and force scale uncertainties, respectively. We have combined the systematic errors linearly. | NODE=Q123SM;LINKAGE=CK |
| 56 GOCKELER 06A use an unquenched lattice computation of the pseudoscalar meson masses with $N_f = 2$ dynamical light quark flavors, and non-perturbative renormalization.  | NODE=Q123SM;LINKAGE=GO |
| 57 JAMIN 06 determine $\bar{m}_s(2 \text{ GeV})$ from the spectral function for the scalar $K\pi$ form factor.  | NODE=Q123SM;LINKAGE=JM |
| 58 MASON 06 extract light quark masses from a lattice simulation using staggered fermions with an improved action, and three dynamical light quark flavors with degenerate $u$ and $d$ quarks. Perturbative corrections were included at NNLO order.  | NODE=Q123SM;LINKAGE=MA |
| 59 NARISON 06 uses sum rules for $e^+e^- \rightarrow \text{hadrons}$ to order $\alpha_s^3$ .  | NODE=Q123SM;LINKAGE=NI |
| 60 BLOSSIER 08 use a lattice computation of pseudoscalar meson masses and decay constants with 2 dynamical flavors and non-perturbative renormalization.  | NODE=Q123SM;LINKAGE=BO |
| 61 NAKAMURA 08 do a lattice computation using quenched domain wall fermions and non-perturbative renormalization.   | NODE=Q123SM;LINKAGE=NM |
| 62 BLUM 07 determine quark masses from the pseudoscalar meson masses using a QED plus QCD lattice computation with two dynamical quark flavors.   | NODE=Q123SM;LINKAGE=BL |
| 63 NARISON 06 obtains the quoted range from positivity of the spectral functions.   | NODE=Q123SM;LINKAGE=NR |
| 64 BAIKOV 05 determines $\bar{m}_s(M_\tau) = 100^{+5+17}_{-3-19}$ from sum rules using the strange spectral function in $\tau$ decay. The computations were done to order $\alpha_s^3$ , with an estimate of the $\alpha_s^4$ terms. We have converted the result to $\mu = 2 \text{ GeV}$ .  | NODE=Q123SM;LINKAGE=BA |
| 65 GAMIZ 05 determines $\bar{m}_s(2 \text{ GeV})$ from sum rules using the strange spectral function in $\tau$ decay. The computations were done to order $\alpha_s^2$ , with an estimate of the $\alpha_s^3$ terms.  | NODE=Q123SM;LINKAGE=GA |
| 66 GORBUNOV 05 use hadronic tau decays to N <sup>3</sup> LO, including power corrections.   | NODE=Q123SM;LINKAGE=GB |
| 67 NARISON 05 determines $\bar{m}_s(2 \text{ GeV})$ from sum rules using the strange spectral function in $\tau$ decay. The computations were done to order $\alpha_s^3$ .  | NODE=Q123SM;LINKAGE=NA |
| 68 AUBIN 04 perform three flavor dynamical lattice calculation of pseudoscalar meson masses, with one-loop perturbative renormalization constant.   | NODE=Q123SM;LINKAGE=AU |
| 69 AOKI 03 uses quenched lattice simulation of the meson and baryon masses with degenerate light quarks. The extrapolations are done using quenched chiral perturbation theory. Determines $m_s=113.8 \pm 2.3^{+5.8}_{-2.9}$ using $K$ mass as input and $m_s=142.3 \pm 5.8^{+22}_{-0}$ using $\phi$ mass as input. We have performed a weighted average of these values.   | NODE=Q123SM;LINKAGE=AO |
| 70 AOKI 03B uses lattice simulation of the meson and baryon masses with two dynamical light quarks. Simulations are performed using the $\mathcal{O}(a)$ improved Wilson action.  | NODE=Q123SM;LINKAGE=AI |
| 71 BECIREVIC 03 perform quenched lattice computation using the vector and axial Ward identities. Uses $\mathcal{O}(a)$ improved Wilson action and nonperturbative renormalization. They also quote $\bar{m}/m_s=24.3 \pm 0.2 \pm 0.6$ .   | NODE=Q123SM;LINKAGE=BE |
| 72 CHIU 03 determines quark masses from the pion and kaon masses using a lattice simulation with a chiral fermion action in quenched approximation.   | NODE=Q123SM;LINKAGE=CH |
| 73 GAMIZ 03 determines $m_s$ from SU(3) breaking in the $\tau$ hadronic width. The value of $V_{us}$ is chosen to satisfy CKM unitarity.  | NODE=Q123SM;LINKAGE=G1 |
| 74 GAMIZ 03 determines $m_s$ from SU(3) breaking in the $\tau$ hadronic width. The value of $V_{us}$ is taken from the PDG.   | NODE=Q123SM;LINKAGE=G2 |

WEIGHTED AVERAGE  
 $94.9 \pm 1.3$  (Error scaled by 1.4)



## OTHER LIGHT QUARK MASS RATIOS

### $m_s/m_d$ MASS RATIO

| VALUE | DOCUMENT ID | TECN | COMMENT |
|-------|-------------|------|---------|
|-------|-------------|------|---------|

#### 17-22 OUR EVALUATION

• • • We do not use the following data for averages, fits, limits, etc. • • •

|                |              |     |                  |
|----------------|--------------|-----|------------------|
| 20.0           | 75 GAO       | 97  | THEO             |
| $18.9 \pm 0.8$ | 76 LEUTWYLER | 96  | THEO Compilation |
| 21             | 77 DONOGHUE  | 92  | THEO             |
| 18             | 78 GERARD    | 90  | THEO             |
| 18 to 23       | 79 LEUTWYLER | 90B | THEO             |

75 GAO 97 uses electromagnetic mass splittings of light mesons.

76 LEUTWYLER 96 uses a combined fit to  $\eta \rightarrow 3\pi$  and  $\psi' \rightarrow J/\psi (\pi, \eta)$  decay rates, and the electromagnetic mass differences of the  $\pi$  and  $K$ .

77 DONOGHUE 92 result is from a combined analysis of meson masses,  $\eta \rightarrow 3\pi$  using second-order chiral perturbation theory including nonanalytic terms, and  $(\psi(2S) \rightarrow J/\psi(1S)\pi)/(\psi(2S) \rightarrow J/\psi(1S)\eta)$ .

78 GERARD 90 uses large  $N$  and  $\eta$ - $\eta'$  mixing.

79 LEUTWYLER 90B determines quark mass ratios using second-order chiral perturbation theory for the meson and baryon masses, including nonanalytic corrections. Also uses Weinberg sum rules to determine  $L_7$ .

### $m_s/\bar{m}$ MASS RATIO

$$\bar{m} \equiv (m_u + m_d)/2$$

| VALUE | DOCUMENT ID | TECN |
|-------|-------------|------|
|-------|-------------|------|

**27.5  $\pm$  1.0 OUR EVALUATION** See the ideogram below. [27  $\pm$  1 OUR 2012 EVALUATION]

|                             |             |     |      |
|-----------------------------|-------------|-----|------|
| 26.8 $\pm$ 1.4              | 80 AOKI     | 11A | LATT |
| 27.53 $\pm$ 0.20 $\pm$ 0.08 | 81 DURR     | 11  | LATT |
| 27.3 $\pm$ 0.9              | 82 BLOSSIER | 10  | LATT |
| 28.8 $\pm$ 1.65             | 83 ALLTON   | 08  | LATT |
| 27.3 $\pm$ 0.3 $\pm$ 1.2    | 84 BLOSSIER | 08  | LATT |
| 23.5 $\pm$ 1.5              | 85 OLLER    | 07A | THEO |

• • • We do not use the following data for averages, fits, limits, etc. • • •

|                |          |    |      |
|----------------|----------|----|------|
| 27.4 $\pm$ 0.4 | 86 AUBIN | 04 | LATT |
|----------------|----------|----|------|

80 AOKI 11A determine quark masses from a lattice computation of the hadron spectrum using  $N_f = 2 + 1$  dynamical flavors of domain wall fermions.

81 DURR 11 determine quark mass from a lattice computation of the meson spectrum using  $N_f = 2 + 1$  dynamical flavors. The lattice simulations were done at the physical quark mass, so that extrapolation in the quark mass was not needed.

82 BLOSSIER 10 determines quark masses from a computation of the hadron spectrum using  $N_f=2$  dynamical twisted-mass Wilson fermions.

83 ALLTON 08 use a lattice computation of the  $\pi$ ,  $K$ , and  $\Omega$  masses with 2+1 dynamical flavors of domain wall quarks, and non-perturbative renormalization.

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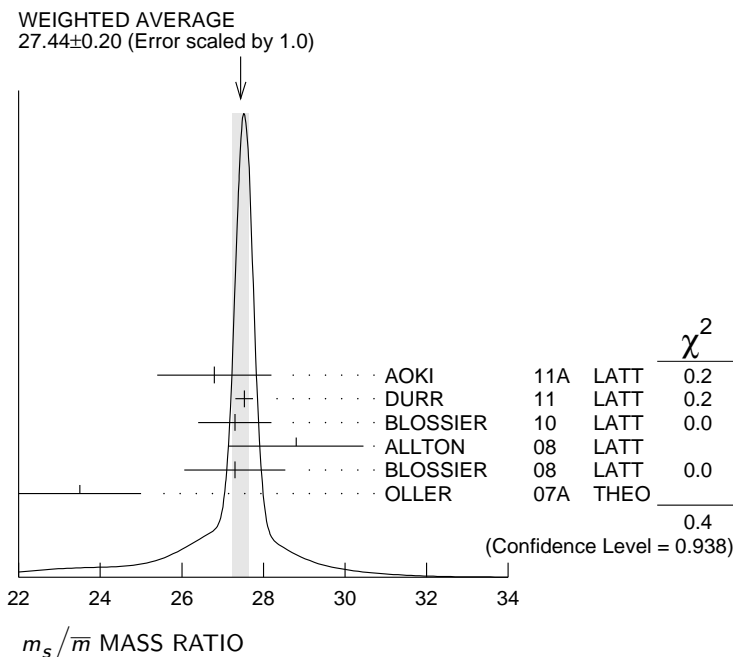
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NODE=Q123MR5;LINKAGE=BS

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- 84 BLOSSIER 08 use a lattice computation of pseudoscalar meson masses and decay constants with 2 dynamical flavors and non-perturbative renormalization.
- 85 OLLER 07A use unitarized chiral perturbation theory to order  $p^4$ .
- 86 Three flavor dynamical lattice calculation of pseudoscalar meson masses.

NODE=Q123MR5;LINKAGE=BO

NODE=Q123MR5;LINKAGE=OL  
NODE=Q123MR5;LINKAGE=AU**Q MASS RATIO**

$$Q \equiv \sqrt{(m_s^2 - \bar{m}^2)/(m_d^2 - m_u^2)}; \quad \bar{m} \equiv (m_u + m_d)/2$$

| VALUE | DOCUMENT ID | TECN |
|-------|-------------|------|
|-------|-------------|------|

• • • We do not use the following data for averages, fits, limits, etc. • • •

|          |                   |      |
|----------|-------------------|------|
| 22.8±0.4 | 87 MARTEMYA... 05 | THEO |
| 22.7±0.8 | 88 ANISOVICH 96   | THEO |

87 MARTEMYANOV 05 determine  $Q$  from  $\eta \rightarrow 3\pi$  decay.

88 ANISOVICH 96 find  $Q$  from  $\eta \rightarrow \pi^+ \pi^- \pi^0$  decay using dispersion relations and chiral perturbation theory.

NODE=Q123MR3

NODE=Q123MR3  
NODE=Q123MR3NODE=Q123MR3;LINKAGE=MA  
NODE=Q123MR3;LINKAGE=D**LIGHT QUARKS ( $u, d, s$ ) REFERENCES**

|              |     |                |   |                               |
|--------------|-----|----------------|---|-------------------------------|
| FRITZSCH     | 12  | NP B865 397    | P. Fritzsch <i>et al.</i>                     | (ALPHA Collab.)               |
| AOKI         | 11A | PR D83 074508  | Y. Aoki <i>et al.</i>                         | (RBC-UKQCD Collab.)           |
| DURR         | 11  | PL B701 265    | S. Durr <i>et al.</i>                         | (BMW Collab.)                 |
| BAZAVOV      | 10  | RMP 82 1349    | A. Bazavov <i>et al.</i>                      | (MILC Collab.)                |
| BLOSSIER     | 10  | PR D82 114513  | B. Blossier <i>et al.</i>                     | (ETM Collab.)                 |
| BLUM         | 10  | PR D82 094508  | T. Blum <i>et al.</i>                         |                               |
| DAVIES       | 10  | PRL 104 132003 | C.T.H. Davies <i>et al.</i>                   | (HPQCD Collab.)               |
| MCNEILE      | 10  | PR D82 034512  | C. McNeile <i>et al.</i>                      | (HPQCD Collab.)               |
| DOMINGUEZ    | 09  | PR D79 014009  | C.A. Dominguez <i>et al.</i>                  |                               |
| ALLISON      | 08  | PR D78 054513  | I. Allison <i>et al.</i>                      | (HPQCD Collab.)               |
| ALLTON       | 08  | PR D78 114509  | C. Allton <i>et al.</i>                       | (RBC and UKQCD Collab.)       |
| BLOSSIER     | 08  | JHEP 0804 020  | B. Blossier <i>et al.</i>                     | (ETM Collab.)                 |
| DEANDREA     | 08  | PR D78 034032  | A. Deandrea, A. Nehme, P. Talavera            |                               |
| DOMINGUEZ    | 08A | JHEP 0805 020  | C.A. Dominguez <i>et al.</i>                  |                               |
| DOMINGUEZ... | 08B | PL B660 49     | A. Dominguez-Clarimon, E. de Rafael, J. Taron |                               |
| ISHIKAWA     | 08  | PR D78 011502  | T. Ishikawa <i>et al.</i>                     | (CP-PACS and JLQCD Collab.)   |
| NAKAMURA     | 08  | PR D78 034502  | Y. Nakamura <i>et al.</i>                     | (CP-PACS Collab.)             |
| BLUM         | 07  | PR D76 114508  | T. Blum <i>et al.</i>                         | (RBC Collab.)                 |
| OLLER        | 07A | EPJ A34 371    | J.A. Oller, L. Roca                           |                               |
| CHETYRKIN    | 06  | EPJ C46 721    | K.G. Chetyrkin, A. Khodjamirian               |                               |
| GOCKELER     | 06  | PR D73 054508  | M. Gockeler <i>et al.</i>                     | (QCDSF, UKQCD Collabs)        |
| GOCKELER     | 06A | PL B639 307    | M. Gockeler <i>et al.</i>                     | (QCDSF, UKQCD Collabs)        |
| JAMIN        | 06  | PR D74 074009  | M. Jamin, J.A. Oller, A. Pich                 |                               |
| MASON        | 06  | PR D73 114501  | Q. Mason <i>et al.</i>                        | (HPQCD Collab.)               |
| NARISON      | 06  | PR D74 034013  | S. Narison                                    |                               |
| PDG          | 06  | JPG 33 1       | W.-M. Yao <i>et al.</i>                       | (PDG Collab.)                 |
| BAIKOV       | 05  | PRL 95 012003  | P.A. Baikov, K.G. Chetyrkin, J.H. Kuhn        |                               |
| GAMIZ        | 05  | PRL 94 011803  | E. Gamiz <i>et al.</i>                        |                               |
| GORBUNOV     | 05  | PR D71 013002  | D.S. Gorbunov, A.A. Pivovarov                 |                               |
| MARTEMYA...  | 05  | PR D71 017501  | B.V. Martemyanov, V.S. Sopov                  |                               |
| NARISON      | 05  | PL B626 101    | S. Narison                                    |                               |
| AUBIN        | 04  | PR D70 031504  | C. Aubin <i>et al.</i>                        | (HPQCD, MILC, UKQCD Collabs.) |
| AUBIN        | 04A | PR D70 114501  | C. Aubin <i>et al.</i>                        | (MILC Collab.)                |
| AOKI         | 03  | PR D67 034503  | S. Aoki <i>et al.</i>                         | (CP-PACS Collab.)             |
| AOKI         | 03B | PR D68 054502  | S. Aoki <i>et al.</i>                         | (CP-PACS Collab.)             |
| BECEVIC      | 03  | PL B558 69     | D. Becirevic, V. Lubicz, C. Tarantino         |                               |
| CHIU         | 03  | NP B673 217    | T.-W. Chiu, T.-H. Hsieh                       |                               |
| GAMIZ        | 03  | JHEP 0301 060  | E. Gamiz <i>et al.</i>                        |                               |
| NELSON       | 03  | PRL 90 021601  | D. Nelson, G.T. Fleming, G.W. Kilcup          |                               |
| GAO          | 97  | PR D56 4115    | D.-N. Gao, B.A. Li, M.-L. Yan                 |                               |
| ANISOVICH    | 96  | PL B375 335    | A.V. Anisovich, H. Leutwyler                  |                               |
| LEUTWYLER    | 96  | PL B378 313    | H. Leutwyler                                  |                               |
| DONOGHUE     | 92  | PRL 69 3444    | J.F. Donoghue, B.R. Holstein, D. Wyler        | (MASA+)                       |
| GERARD       | 90  | MPL A5 391     | J.M. Gerard                                   | (MPIM)                        |
| LEUTWYLER    | 90B | NP B337 108    | H. Leutwyler                                  | (BERN)                        |

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